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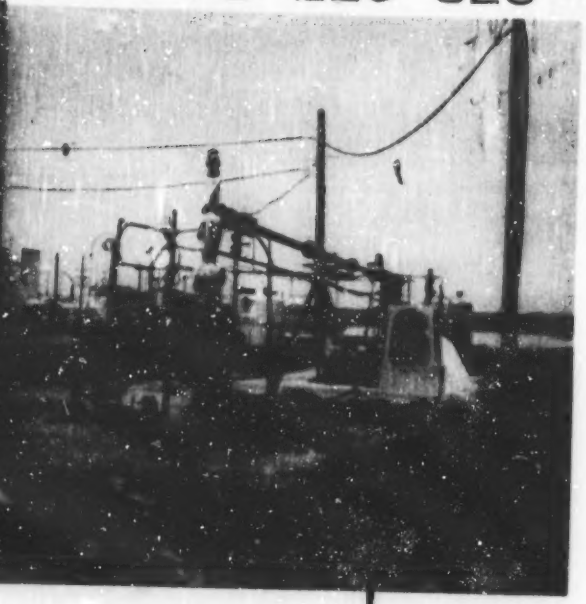
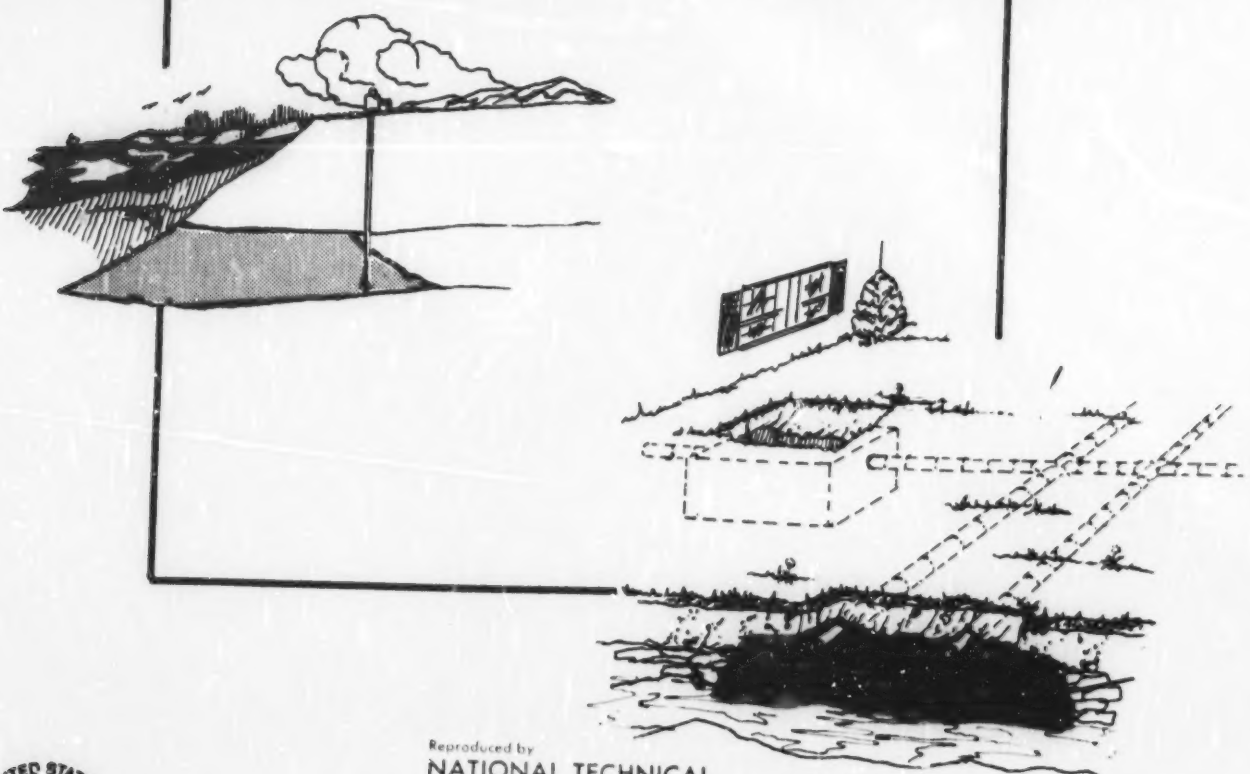
Subsurface Pollution Problems in the United States





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SUBSURFACE POLLUTION PROBLEMS IN THE UNITED STATES,

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Ballentine, R.K., Reznek, S.R., and Hall, C.W.

Environmental Protection Agency, Washington, D C, Fresh Water Pollution Control Section

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Sources of subsurface water contamination can generally be assigned to one of three basic categories: (1) the direct introduction of pollutants deep within the earth by injection through wells; (2) percolation of pollutants from surface and near surface sources such as septic tanks, leaching ponds, sanitary landfills, and pesticides and fertilizers used in agricultural practices; and (3) intrusion of salt water into fresh-water aquifers as a result of reductions in fresh-water flow in coastal areas or the breaching of impervious strata in inland areas. These pollution problems are reviewed concerning the increasing demands for water of acceptable quality for the various types of water needs in the United States. (Woodard--USGS)

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T.H. Woodard 7/26/72 US Geological Survey, Water Res. Div.

SUBSURFACE POLLUTION PROBLEMS IN THE UNITED STATES

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Applied Technology Division
Water Quality Protection Branch
Fresh Water Pollution Control Section
Washington, D.C. 20460

May 1972

Technical Studies Report: TS-00-72-02

Introduction

Historically ground water in the United States has been a quantitatively minor water source; its only major role being domestic water supply for individual homes or small communities. Today, ground water accounts for nearly 20 percent of the Nation's requirements for water and has been viewed by some as the answer to the Nation's water supply problem. It has been estimated that the total useable ground water in storage is equivalent in volume to the discharge of all the Nation's rivers for 35 years.[1] However, difficulties in locating, evaluating, developing, and managing ground water supplies make full use of this enormous reserve a distant reality.

Estimates of water use in 1954 and projections for 1980 and 2000 suggest the increasing importance of our ground water resources. Total water use is expected to increase from an extimated 300 billion gallons per day (bgd) in 1954, to 599 bgd in 1980 and 888 bgd in 2000; nearly a 3-fold increase in less than 50 years. Municipal use is expected to increase by 250 percent, and manufacturing use by 720 percent in the same time

period.[2] In many areas of the country, surface waters have already become so degraded that they are unfit for many uses without extensive and costly treatment. It must be expected that our ground water reservoirs will be increasingly used to fulfill our requirements for high quality water.

Until recently, minimal consideration has been given to the effects on the subsurface environment as a result of waste disposal practices. The dimishing capabilities of surface waters to receive effluents without violation of water quality standards has made the direct emplacement of wastes in the subsurface increasingly more attractive to waste water dischargers. The effects of subsurface water pollution, and the fate of pollutants in the subsurface are not well understood. Insufficient knowledge of the hydrology and hydro-mechanics of the ground water region is presently available to confidently manage this complex system. Other than basic facts concerning mechanisms of flow due to gravity head differences;

predictive relationships for ground water velocity, mixing, dispersion, and stratification still require refinement. It seems evident, however, that ground water pollution is essentially irreversible. Once an aquifer is contaminated by percolation from surface sources, saltwater intrusion, or from injected wastes, it is difficult, or in most cases unfeasible, to remove the contaminants by flushing or pumping and restore the aquifer to its original condition.

Sources of subsurface water contamination can generally be assigned to one of three basic categories: 1) The direct introduction of pollutants deep within the earth by injection through wells, 2) percolation of pollutants from surface and near surface sources such as septic tanks, leaching ponds, sanitary landfills, and pesticides and fertilizers used in agricultural practices, and 3) intrusion of salt water into fresh water aquifers as a result of reductions in fresh water flow in coastal areas or the breaching of impervious strata in inland areas.

Deep Well Injection

Deep well injection is the emplacement of wastes within the earth, usually below the water table and beneath a confining strata which serves to isolate the wastes from potable water supplies or other valuable or potentially valuable resources (figure 1). The feasibility of injection of liquid wastes deep within the earth is suggested by the enormous capacity of subsurface fluid storage space. The earth, however, contains few empty spaces and waste liquids can only be accomodated by compressing or displacing existing fluids or by compressing or deforming the surrounding strata. The possible consequences of high pressure waste injection include the displacement of saline waters quite distant from the injection site, the fracturing of geologic strata that could result in pollution of high quality aquifers, the migration of wastes and native fluids along existing or created fractures or faults, the upward transfer of pollutants along well casings and even the gross readjustment of

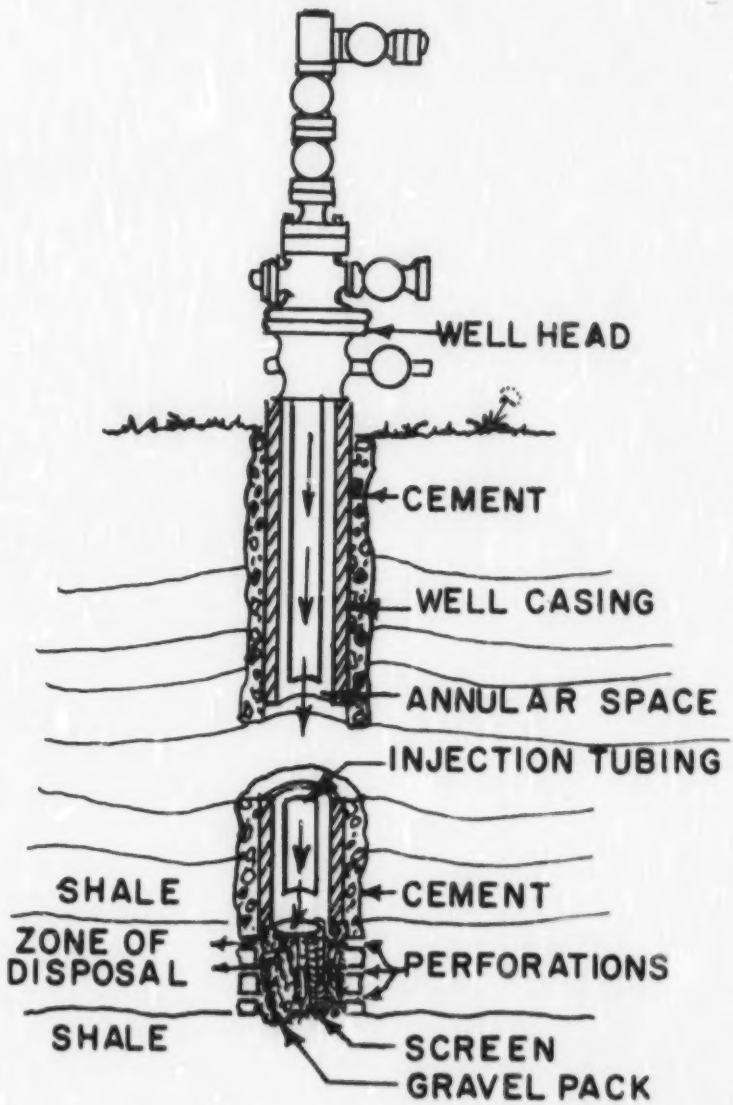


Figure 1

Typical Waste Injection Well System

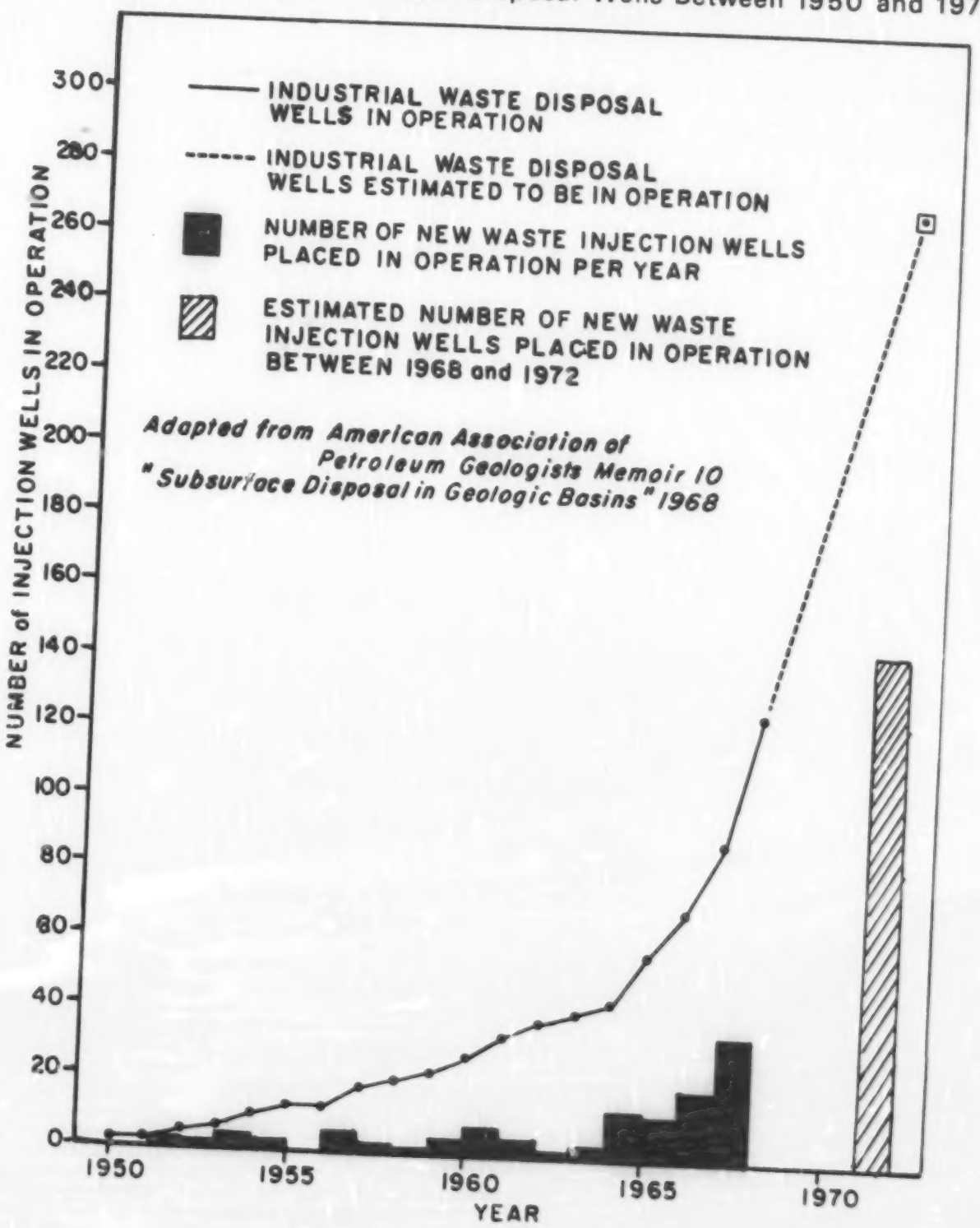
the surrounding strata. An example of the latter is the now infamous Denver Arsenal injection well where the injection of wastes is believed to have triggered a series of minor earthquakes. The injection of fluids, within the earth, is not a problem confined to hydrostatics. Included is the distribution of the initial pressure increases and their effects on the surrounding rock matrix. Radioactive and chemically unstable wastes may produce heat and pressure after they have been injected. It is possible that injected wastes will react with the fluids and minerals of the injection horizon changing the permeability or strength of the surrounding strata. Determining the compatibility of the waste solution and the fluids and minerals of the injection horizon on the basis of pH or specified salt concentrations is risky. The identification of strata where injection is feasible is not difficult, this however, must not be construed to imply an adequate understanding of the effects of injection of a given amount of fluid.

Currently, there are two distinct types of deep well injection practiced in the United States. The first, and by far the largest in terms of number of wells and volume of fluids injected, is the return of brines or other fluids to the aquifers from which they were extracted. This is a very common practice in the oil and gas industry where approximately 10,000 acre-feet of wastes are injected yearly through many thousands of wells in the oil producing States[3]. The second type is the injection of liquid industrial, municipal, or low level radioactive wastes. Currently a minor practice compared to the reinjection of brines, the number of industrial and municipal injection wells has increased from approximately 125 in 1968 to over 270 at present. This practice can be expected to continue to increase as surface disposal becomes more controlled and more costly (figure 2).

Brine reinjection has been practiced by the petroleum industry for over 50 years, both in water flooding for the secondary recovery of oil, and as a means of

Figure 2

Increase in the Use of Waste Disposal Wells Between 1950 and 1972



disposal of the brines associated with the production of oil. Ideally, the brines are reinjected into the strata from which they were produced, not only disposing of great volumes of liquid material but also preventing land subsidence and facilitating greater oil production. In the reinjection of oil field brines, the most difficult problems of where the fluids go are usually solved or assumed to be solved. A great deal of exploration and documentation of the geologic and hydrologic situation has been made and is available for areas where reinjection is practiced. Unfortunately, the wastes are not always as well confined or as accurately emplaced as would be desired. The contamination of shallow ground water around oil fields is widespread and well recognized. The major area for concern in the reinjection of brines is engineering safeguards. Injection wells must be constructed and operated to guarantee that the brines are entering and being contained in the desired strata.

Industrial and municipal wastes disposed of by deep well injection are generally highly noxious and difficult to treat. There have been accidents, including the now famous earthquakes near the Denver Arsenal injection well, and the blowup of the Hammermill Paper company injection well in 1968. Approximately 150,000 gallons per day of wastes spewed from the Hammermill well into Lake Erie. This waste contained spent sulfite liquor, titanium dioxide, clay, and lignin-like compounds[4].

Deep well injection of wastes is currently being practiced often without adequate controls. Only about one half of the states have regulations concerning waste injection wells and few distinguish between the reinjection of oil field brines and the injection of municipal and industrial wastes. In general the information for proper site selection and well design is not available to controlling authorities. In an attempt to avoid further degradation of the subsurface environment by waste injection the Federal Water

Quality Administration, in October 1970, established a policy (Appendix A) on disposal of wastes by subsurface injection. This policy opposes the subsurface injection of wastes without strict controls and a clear demonstration that no damage to present or potential subsurfaces resources will result from the waste injection. Many of the problems of deep well injection could be eliminated or avoided if it were possible to monitor the fate of wastes that have been injected. The problems associated with monitoring, however, are legion: What is to be monitored, how, and for how long? Certainly the pressures and flows in the injecting wells must be known, but monitoring must also be done at some distance from the injecting well and must supply information that could be used to halt the contamination of adjacent fresh water supplies, or other environmental hazards.

The problems that must be solved to ensure adequate control of deep well injection are: Identifying and classifying areas safe for injection, determining what

volumes of waste can be safely injected, establishing chemical standards for wastes to minimize the dangers of incompatibility with the minerals and fluids of the injection horizon, and development of methods for monitoring and recording deep well injections to ensure the engineering standards of their operation.

Percolation from Surface Sources

By far the major source of contamination of ground water is the wastes which percolate down through the soil to reach the water table. When a contaminant is introduced at or just below the ground surface, it begins to slowly percolate down toward the water table. In the percolation process, the soil acts as a filter and some of the contaminants are removed. The zone above the water table commonly contains air, and aerobic biological degradation can take place. A further process is chemical adsorption. Many substances, and in particular phosphates, will be

adsorbed by or ionexchanged with the soils. Under normal conditions all of these processes; filtration, biodegradation, and adsorption serve to reduce the waste load which reaches the water table. These processes, however, are not effective in removing contaminants such as chlorides, nitrates or pesticides and other non-degradable organic materials. Once the contaminants reach the water table, biodegradation of organics changes from aerobic to anaerobic because of the lack of available oxygen. The adsorption and ion-exchange of minerals have not been thoroughly studied, but it seems reasonable that the soil's capacity for these processes can be exhausted, and that efficiency will decrease with time.

Urban and suburban waste disposal by septic tanks is still very common in the United States (figure 3). Approximately 13 million private septic tank systems serving an estimated 50 million people are in use in the United States today.[5] Tremendous waste loads can filter into the ground water from septic tanks where

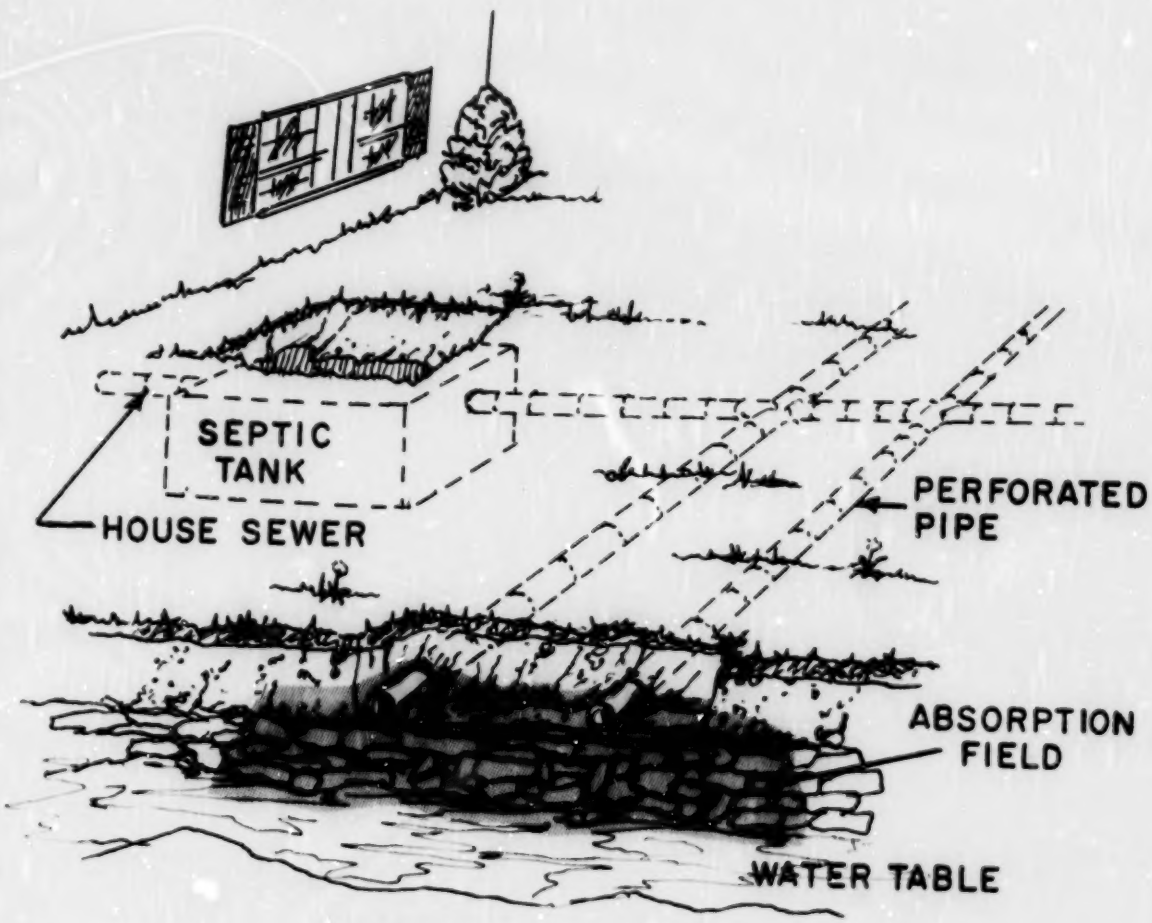


Figure 3
SEPTIC TANK SEWAGE-DISPOSAL SYSTEM

inadequate absorption fields exist and there is a growing tendency to believe that distance of travel implies a delay in the discovery of pollution rather than the removal of wastes. There have been outbreaks of hepatitis in communities which have contaminated the ground water with septic tank effluents.[5] The problem of detergent contamination of ground water is now well known and has been particularly severe in California and New York. Even biodegradable detergents are not degraded once they have entered the ground water where very little oxygen is available.

Seepage or evaporation ponds as waste treatment devices have historically been used by municipalities and industries when surface disposal of waste water into natural water courses was undersirable or unavailable. The use of such methods by industry is becoming more common as disposal to surface water becomes more controlled. Operation of seepage and evaporation ponds permits the percolation of dissolved wastes into the ground water flow.

Refuse dumps and landfills also frequently introduce contamination to the ground water. Since sanitary landfills and dumps are often located in topographically low areas, much of the refuse is often situated very close to or even below the water table. Subsequent decomposition of the wastes or deterioration of sealed containers can introduce contaminants to the ground water supply either by direct contact or by percolation through a short distance in the zone of aeration.

Agriculture is perhaps the major contributor of percolating ground water contaminants. Intensive agricultural practices include the addition of fertilizers, the confined feeding of livestock and the application of large amounts of pesticides. In areas of intensive land use tremendous quantities of nutrients, salts, and organic wastes enter the ground water and degrade its quality. In an attempt to avoid further contamination of both surface and ground waters by agricultural practices, the Environmental Protection

Agency, in January 1972, established a policy (Appendix B) on the control of nutrient runoff from agricultural lands.

In Illinois, thirty percent of all wells less than 25 feet deep contain nitrate (NO_3^{-1}) concentrations in excess of the 45 mg/l Public Health Service Drinking Water Standards recommended limit.[8] The problem of agricultural contamination of ground water can be intensified in arid areas where ground water is used for irrigation. As the water is applied, some is absorbed by the plants, but the salts are retained in the remaining water. The water that filters back to the ground water has an increased salt concentration. If the ground water is recycled, the concentration process can continue until the soil and ground water are too salty to permit the growth of crops. This situation has occurred many times in the past and once fertile areas have become useless. The situation is now occurring in the Southwest.

All of the sources of surface water contamination also affect the ground water. Ground and surface waters are very closely connected and many rivers and lakes discharge to the ground water during all or part of the year. Such waters carry any pollutants they may contain down to the water table.

The build-up of contaminants in ground waters from percolating pollutants is seldom dramatic, and sources of percolating pollutants are both diffuse and diverse, all of which compounds the problems of control and abatement. In the area of percolating pollutants, however, at least two needs warrant immediate research: a) The control and prevention of increased ground water salinity through its use for crop irrigation and return to the water table; and b) the effects of septic tank effluents on ground water, particularly the detergents, pesticides, herbicides, and fertilizers they contain. A better understanding is required of the stratified, laminar flow, and lack of disperison mechanisms in aquifers. Knowledge of constituent removals and

changes affected in the unsaturated and saturaed zones is needed.

Salt Water Intrusion

In many areas of the United States, saline and fresh subsurface waters occur in close proximity. This condition is prevalent in inland areas and ubiquitous in coastal regions. Proximity implies an inherent danger of saline contamination of fresh water resources. In many localities such contamination is a reality.

Salt water intrusion is very rarely a mixing process. Ground water flow is laminar and salt water and fresh water are of different densities. Diffusion processes can therefore be ignored. Intrusion is the process of replacing fresh water with salt water. In theory there is no difference between the process whereby the sea replaces fresh water and other density-caused

processes. The problems of coastal and inland intrusion, if not differing in kind, differ in magnitude, and it is in the coastal areas where the critical and massive intrusion problems usually occur.

If saline and fresh water are in contact, the frontal surface will move in response to changes in the pressure head of either system. Under natural conditions in ground water basins there is a balance between inflow and outflow. In the case of an aquifer in hydraulic continuity with the ocean or other large saline body, there is sufficient pressure and flow to counteract the tendency for the heavier sea water to move inland. When fresh water is removed from the aquifer for use, or when recharge of the aquifer is decreased, the water level is lowered. The lower pressure permits salt water to move into the fresh water zone (figure 4). Intrusion caused in this way is said to result from a reversal or a reduction in the pressure gradient. Parts of Long Island Sound and mainland New York provide a typical example. These

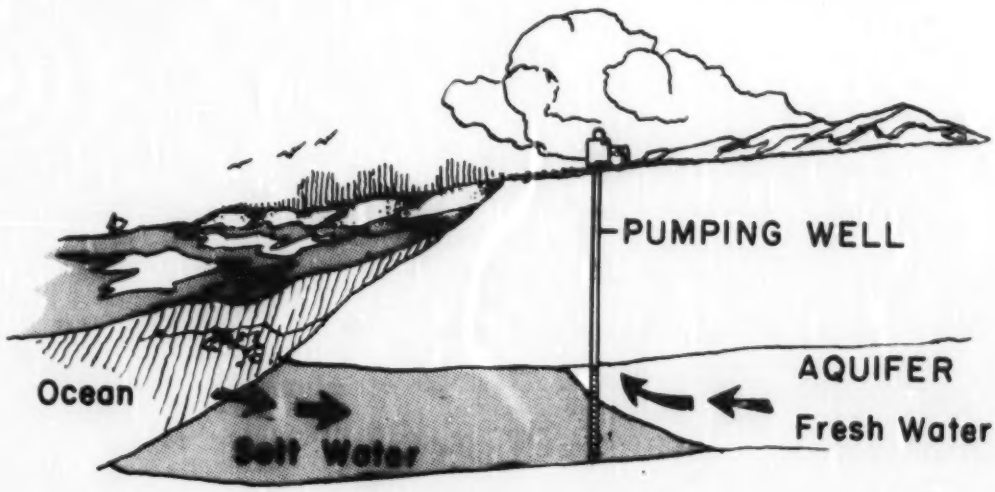


Figure 4

COASTAL SALT WATER INTRUSION CAUSED BY REDUCTION IN FRESH WATER FLOW.

areas are underlain by a wedge shaped mass of unconsolidated sediments that extend to a depth of more than 2,000 feet. Major intrusion has occurred as a result of ground water withdrawal and the decrease in aquifer recharge caused by improved drainage and sewer systems. By the mid 1930's, water levels in parts of Kings and Queens Counties were lowered to as much as 35 feet below sea level.[6] Sea water intrusion resulted. Ground water supplies in the most highly urbanized areas of these counties have been abandoned and water is supplied from the New York City water system. Because of the high rates of pumping and the extension of sewer systems removing a recharge source, the hydraulic imbalance persists and the threat of intrusion increases.

Salt water intrusion almost always has been the inadvertent result of some activity of man as he alters his environment. An even better demonstration of this often results from waterway construction. When natural waterways are deepened or widened, there is the

possibility that materials which have acted as an impermeable blanket between saline waters and underlying fresh waters may be removed. When new waterways which connect inland areas with the sea are constructed, permeable layers may be exposed to saline water, or sea water may be conducted past existing barriers. In either case, a channel for the movement of salt water into fresh water aquifers is created.

On the highly populated Atlantic coast, between Massachusetts and Florida, each of the states is having problems with sea water intrusion.[6] The seriousness of the problems is usually dependent on the intensity of urban and industrial development with its associated extraction and non-return of water. On the West Coast, California has had many problems with sea water intrusion and has spent considerable effort to try to solve or ameliorate the problems. In several places it is now common practice to recharge the ground water with fresh water or treated wastes so that a mound is created between the ground water basin and the salt

water (figure 5). A series of recharge mounds then act as a barrier and allow the ground water basin to be pumped down below sea level. To date, the recharge mound seems to be the only effective method of combating sea water intrusion.

In inland areas, salinity problems are surprisingly widespread. In geologic history, precipitation has washed soluble salts from the soils. These salts moved with the fluids until they arrived in large basins where they were concentrated by evaporation. Approximately two thirds of the conterminous United States is underlain by saline waters containing more than 1,000 mg/l dissolved solids.[6] The problem of salt water intrusion in inland aquifers can be the same as in coastal areas, however, in inland areas there is more likely to be a physical barrier separating salt water and fresh water aquifers. Care must be taken that these barriers are not ruptured. A major source of contamination is the breaching of confining layers by drilling or mining. In such instances, the salt

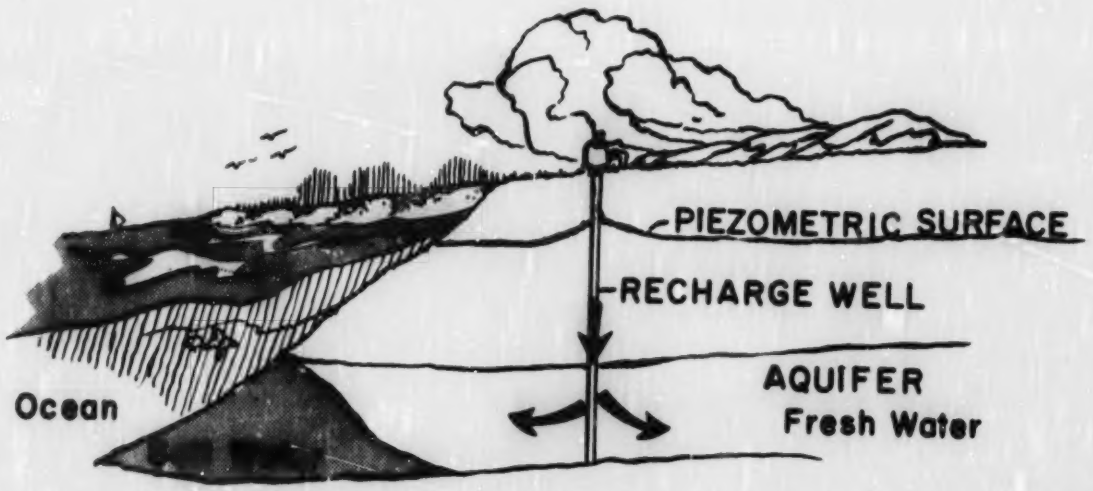


Figure 5

CONTROL OF SALT WATER INTRUSION BY USE OF A RECHARGE MOUND

water can move along the channels which are created and flow into fresh water aquifers.

In the area of salt water intrusion, additional research is needed to develop new methods for prevention and correction of coastal salt water intrusion. Present methods incorporating artifically recharged domes of fresh water may become increasingly less desirable as fresh water volume requirements increase causing increased ground water extraction to serve the needs of increased population.

Controls

An additional measure needed for the protection of subsurface waters is a waste effluent permit system similar to that currently applicable to to surface waters under the 1899 Refuse Act. Deep well disposal of wastes must be controlled by laws or regulations requiring the issuance of permits based on information about the disposal site and the wastes to be injected. Surface and near surface disposal regulations, usually

designed to prohibit surface nuisances, must be reevaluated in terms of protection of water quality in the subsurface.

Currently, the authority of the Federal Government in the control of subsurface pollution is ill-defined. Federal legislation now being considered in the Congress, however, would provide for an expanded government role at both the Federal and State levels for the protection of the subsurface environment. Provisions of the proposed legislation include: The development of state laws and regulations, pursuant to Federal guidelines, for subsurface water protection; development of guidelines, information and criteria for subsurface disposal standards; increased research activity in the scientific factors affecting subsurface waste disposal; development of a subsurface pollution surveillance and monitoring program; development of a state enforcement system which must include a permit system for subsurface waste disposal; development of subsurface disposal site criteria; development of

injection well construction and operation standards; increased state program grants for implementing subsurface pollution control programs; and development of a nationwide program administered by the states pursuant to Federal guidelines to regulate land and underground disposal of wastes toxic to human health.

A comprehensive approach to the protection of subsurface waters will require a concerted, unified effort at the Federal, State, and local levels of government. If we are to consistently produce the enormous quantities of high quality water that the future will demand and if we are to avoid the same degradation of our ground water resources that our surface water resources have undergone, management of withdrawal and recharge must be instituted. Research and technology must combine efforts to fill the basic knowledge gaps in the earth sciences that allow understanding of the causes and permit prediction of the effects of subsurface water pollution.

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FEDERAL WATER QUALITY ADMINISTRATION
WASHINGTON, D.C. 20242

ORDER

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COM 5010.10
October 15, 1970

SUBJECT: Policy on Disposal of Wastes by Subsurface Injection

1. PURPOSE. This order establishes FWQA policy on the disposal of wastes by subsurface injections.

2. BACKGROUND.

a. The disposal and storage of liquid wastes by subsurface injections are being increasingly considered, especially by industries facing enforcement of water quality standards. This is because of the diminishing capabilities of surface waters to receive effluents without violation of standards, and the apparent lower costs of this method of disposal over conventional and advanced waste treatment techniques.

b. The effects of underground pollution and the fate of injected materials are uncertain with today's knowledge. These wastes could well result in serious pollution damage and require a more complex and costly solution on a long-term basis.

c. Improper injection of municipal or industrial wastes to the subsurface could result in serious pollution of water supplies or other environmental hazards.

3. POLICY.

a. FWQA is opposed to the disposal or storage of wastes by subsurface injection without strict controls and a clear demonstration that such wastes will not interfere with present or potential use of subsurface water supplies, contaminate interconnected surface waters, or otherwise damage the environment.

b. All proposals for subsurface injection of wastes shall be critically evaluated to determine that:

(1) Alternative measures have been explored and found less satisfactory in terms of environmental protection;

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(2) Appropriate preinjection tests have been made to allow prediction of the fate of wastes to be injected;

(3) There is adequate evidence to demonstrate that such injection will not interfere with present or potential use of water resources nor result in other environmental hazards;

(4) Best practical measures for pretreatment of wastes have been applied;

(5) The subsurface injection system has been designed and constructed using the best available techniques, equipment, and design criteria;

(6) Provisions for adequate and continuous monitoring of the injection operation and resulting effects of the injection on the environment have been made; and

(7) Appropriate provision will be made for plugging such wells at horizons below present or potential sources of water supply when their use for disposal is discontinued.

c. Where subsurface injection of wastes is practiced, it will be recognized as a temporary means of ultimate disposal to be discontinued when alternatives enabling greater environmental protection become available.

4. IMPLEMENTATION. FWQA will apply this policy to the extent of its authorities conducting all program activities, including regulatory acti s, research and development, control of pollution from Federal ins llations, technical assistance to the States, and the administration of the construction grants, State program grants, and basin planning grants programs.

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David D. Dominick
Commissioner

Appendix B

SUBJECT: Policy on Control of Nutrient Runoff from Agricultural Lands

1. PURPOSE. To establish EPA policy on the control of nutrients from agricultural lands.

2. BACKGROUND.

a. The streams, lakes and estuaries of any area reach an equilibrium under the natural conditions of the area. This applies to the nutrients reaching these waters and the utilization of the nutrients by the aquatic biota that inhabit the waters. Man's activities tend to upset this equilibrium and generally result in increased nutrients and other pollutants reaching the waters. The increased water nutrient levels lead to problems that include excessive aquatic plant growths with the attendant oxygen problems that are associated with decomposition processes, and to an acceleration in the aging of the water body.

b. Along with industrial and municipal sources, man's agricultural activities contribute nutrients to the waterways. If the quality of the surface and ground waters of the nation is to be improved, and further degradation prevented, the nutrients resulting from agricultural activities must be controlled along with those from municipal and industrial sources.

c. Nutrients from agricultural activities, either carried by dislodged sediments or dissolved in the drainage water include: those from native soils; decaying crop residues; fertilizers applied to the land, both organic and inorganic; and animal wastes.

3. POLICY.

a. The management of agricultural nutrients will require: appropriate limitation of erosion and sediment runoff; the efficient use of applied fertilizers by the plants; the application of fertilizers under the right climatic and crop growth conditions; and the retention of animal wastes on the land. Management programs should be planned and implemented for complete drainage basins. However, maximum use should be made now of existing programs that are available to individual farms or groups of farms.

b. Existing Federal, State, and local programs for control of erosion and sediment runoff should be implemented on an accelerated basis, and, where applicable, the upper

reaches of watersheds should be attacked first while attacking critical problems in other areas that are amenable to early solutions. Projects designed for erosion and sediment control should include nutrient runoff control measures. The inclusion of such measures and acceleration of the implementation of erosion and sediment control projects will result in reductions of the nutrients reaching the streams while at the same time retaining the soils on the agricultural lands.

c. The development of fertilizer application management plans will require full evaluation of the nutrient availablility and retention capability of various soil types of the appropriate agricultural area. The capability of existing programs, such as those of the U.S. Department of Agriculture and State and local Agricultural Agencies should be brought to bear toward developing the essential information for complete watersheds and soil structure types at an early date. Starting now with available information, guidelines for fertilizer application, including maximum recommended rates, should be developed. The voluntary use of the guidelines in the fertilizer program for individual farms should be encouraged through a strong effort by the presently available educational programs of Federal, State, and local agencies and educational institutions, and through technical assistance. Success of the educational approach must be adequately monitored in critical areas to determine the needs for other approaches to achieving necessary levels of nutrient control. Consideration should be given to requiring adherence to certain fertilizer application guidelines as a condition of eligibility for selected forms of governmental assistance.

d. Animal wastes, principally manures, serve as both a source of nutrients and as a soil builder when applied to agricultural lands. Programs to retain the manures on the land, and incorporate them into the soil should be developed and implemented as part of the overall nutrient management program of a watershed while greatly increasing the use of already proven animal waste control programs for individual farms or animal feeding operations.

(1) Animal wastes should not be applied to farm lands under adverse soil or weather conditions except when planned methods will insure that they remain on the land. Storage of the wastes in designed structures until they can be incorporated into the soil should be used.

(2) Watering and feeding points should be established away from waterways along with the establishment of runoff

and erosion control measures to prevent the concentration of animal wastes in the vicinity of the streams. When a high density of animals is created through confinement, fencing of the streams traversing such areas should be used as a means of preventing water pollution by the wastes of the confined animals and the physical destruction of the streambeds and banks.

4. IMPLEMENTATION. EPA will apply this policy to the extent of its authorities in conducting all program activities, including regulatory activities, research and development, technical assistance, control of pollution from Federal institutions, and the administration of the construction grants, State program grants, and basin planning grants programs.

William D. Ruckelshaus
Administrator

DATE: January 14, 1972

U. S. GOVERNMENT PRINTING OFFICE: 1972—486-482 (1-0)